

Measuring Impact Velocities of Non-Lethal Weapons

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Outline

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- Overview
- Blunt Trauma Type Non-Lethal Weapons (NLW)
- Velocity Measurements
- Experimental Setup
- Results - Modeling Clay and Styrofoam®
- Discussion of Results
- Summary
- Recommendations



Overview

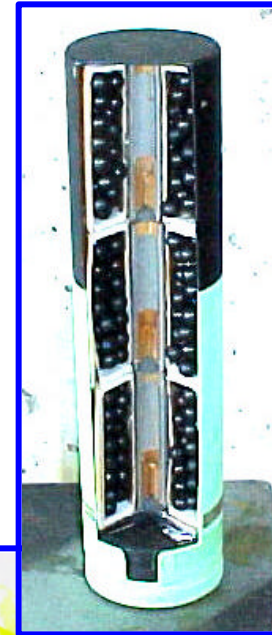
- **Increase emphasis for Non-Lethal Weapons (NLW)**
- **Need for Human Effects model specifically for NLW**
- **Identify and quantify important parameters that describe NLW**
 - **For a blunt trauma type munition, such as the XM99 Stingball Grenade - impact velocity, mass and shape**



Blunt Trauma Type NLW

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- **XM99 Blunt Trauma Grenade**
 - 100m range
 - 3 cartridges containing 0.32 cal rubber stingballs
 - explosively dispersed
- **Optimization of the XM99**
 - Burster charge
 - Stingball impact velocity
 - Human Effects studies





Velocity Measurements

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- **Many techniques available**
 - **High-speed film/video**
 - **X-Rays**
 - **Various types of ballistic screens**
- **Problems with explosive dissemination on velocity measurement techniques**
 - **Flash “White-Out”**
 - **Debris**
 - **Random projectile flight paths**
 - **Expense/Time**



Indirect Velocity Measurements

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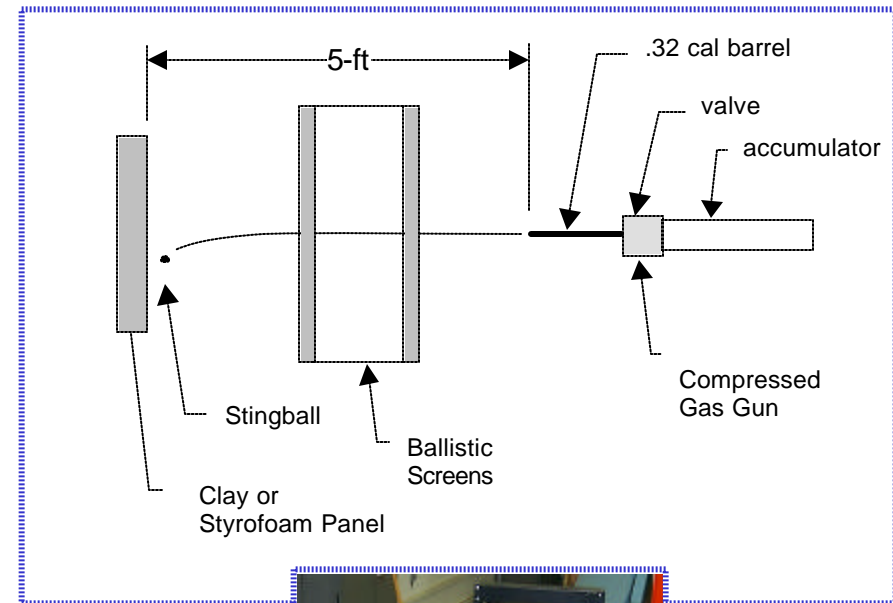
- **NIJ Ballistic Resistance of Police Body Armor**
 - **NIJ Standard 0101.03**
 - **Uses penetration into modeling clay as a “Pass/Fail” indicator.**
 - **If penetration into clay is repeatable for this application why not use it to determine impact velocity?**
- **Indirect Velocity Measurements**
 - **Modeling Clay - Roma Plastilina #1**
 - **Rigid Construction Styrofoam® Insulation - extruded polystyrene board insulation**
 - **Correlate impact velocity with depth of penetration**



Experimental Setup

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- **Compressed Gas Gun**
 - 0.32 cal barrel
 - single shot
 - 180 - 600 fps
- **Stingball velocity measured by ballistic screens**
- **Penetration depth measured with machinist depth gauge**
- **10 shots each at 5 different velocities**

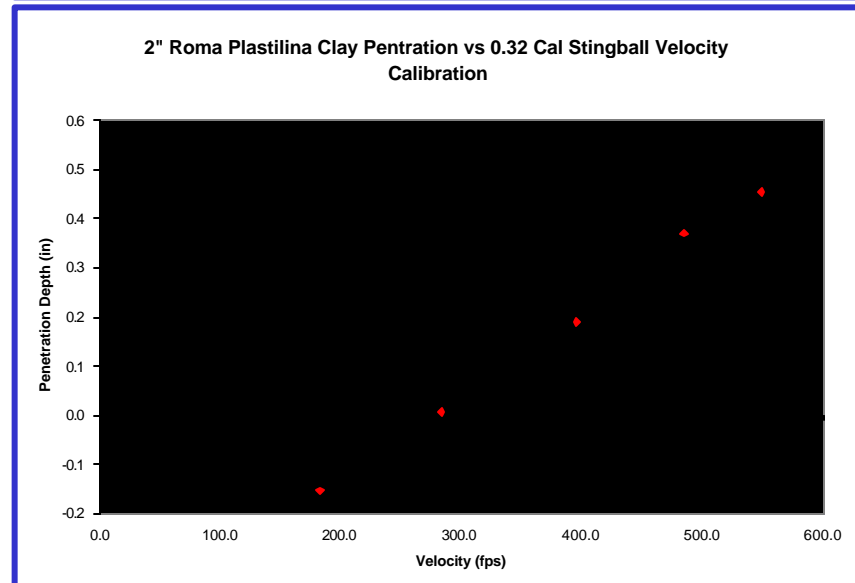
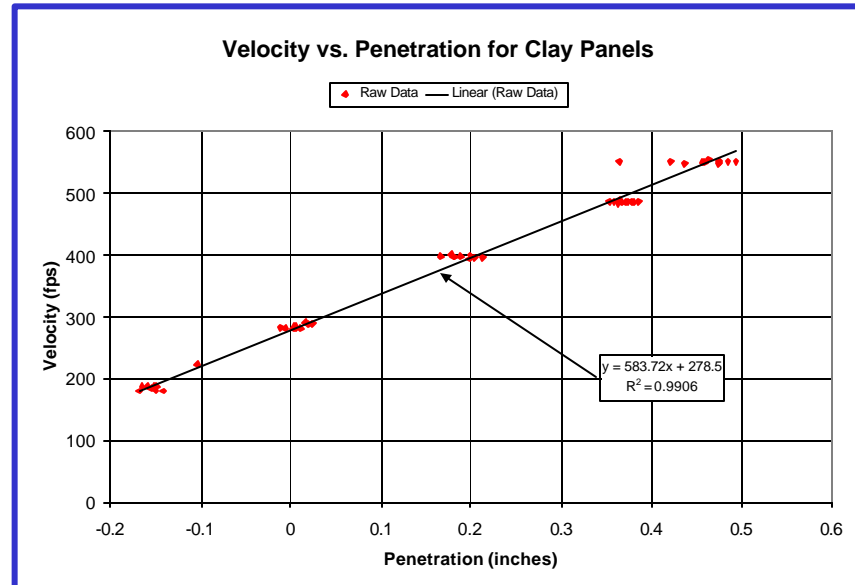




Modeling Clay Results

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- 2x2-ft x 2-in deep panel
- 10 shots at 5 velocities
- good repeatability

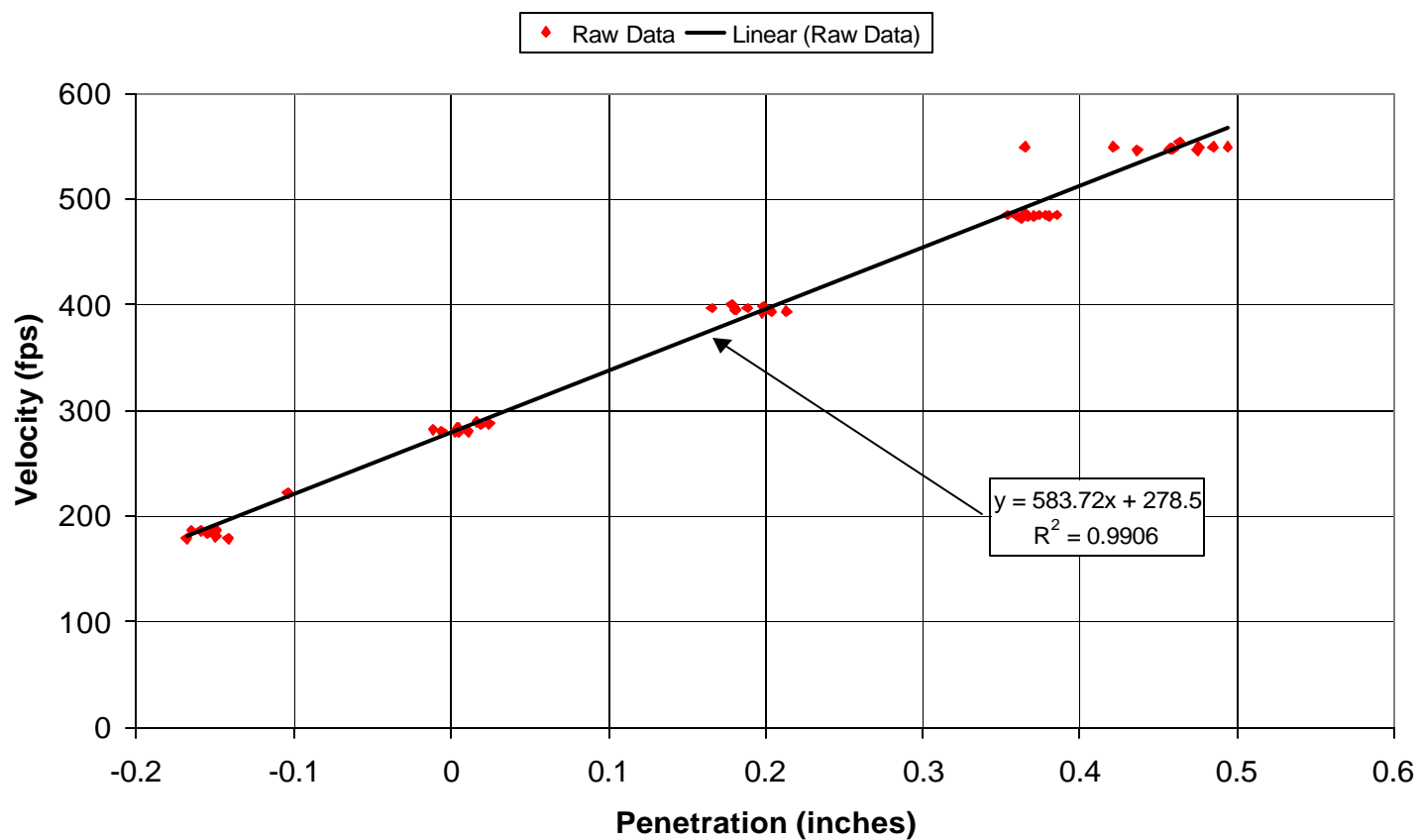




Clay Panel Results

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Velocity vs. Penetration for Clay Panels

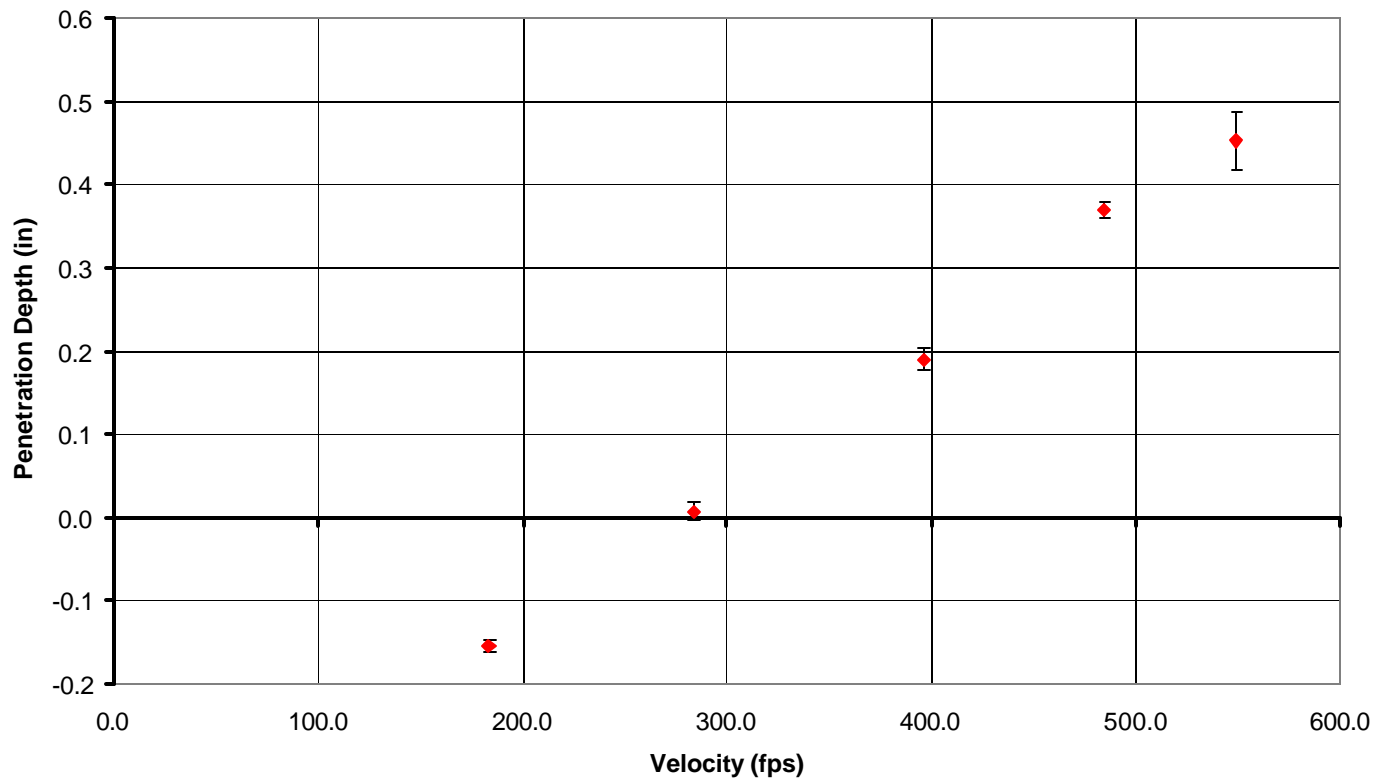




Clay Panel Results

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2" Roma Plastilina Clay Penetration vs 0.32 Cal Stingball Velocity Calibration

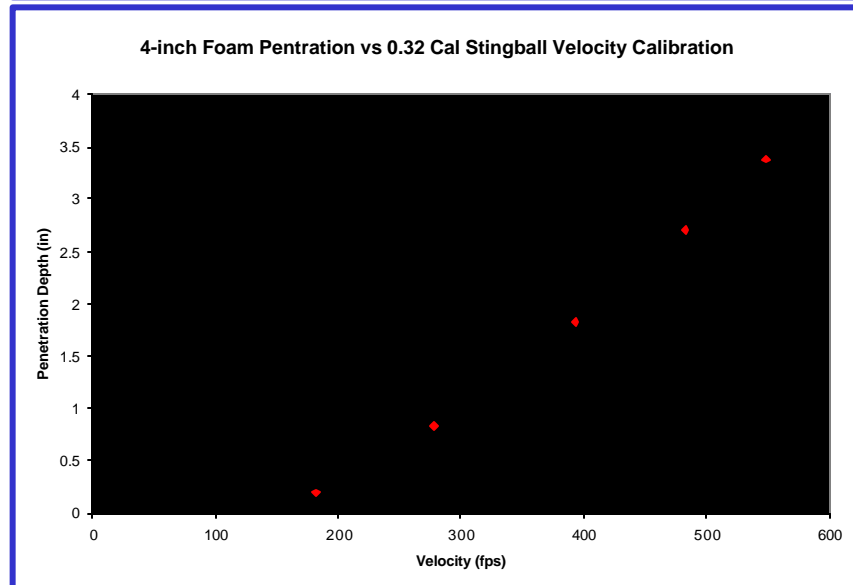
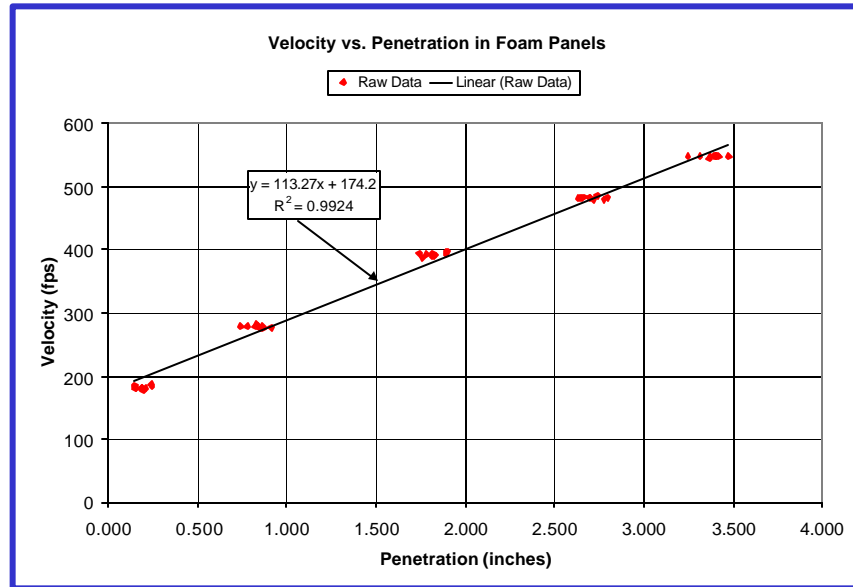




Styrofoam[®] Results

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- 2x2-ft x 4-in deep panel
- 10 shots at 5 velocities
- very good repeatability

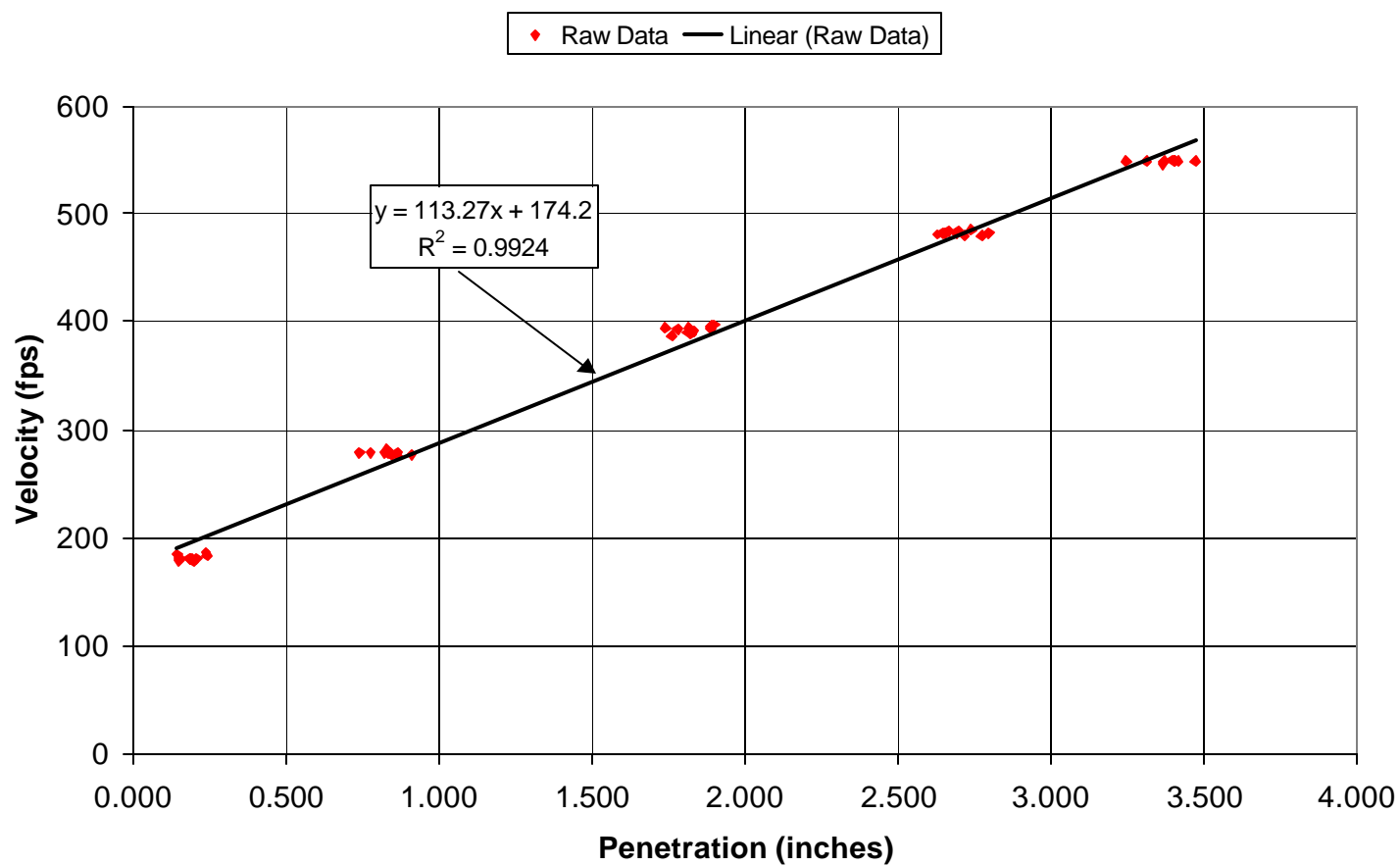




Styrofoam[®] Results

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Velocity vs. Penetration in Foam Panels

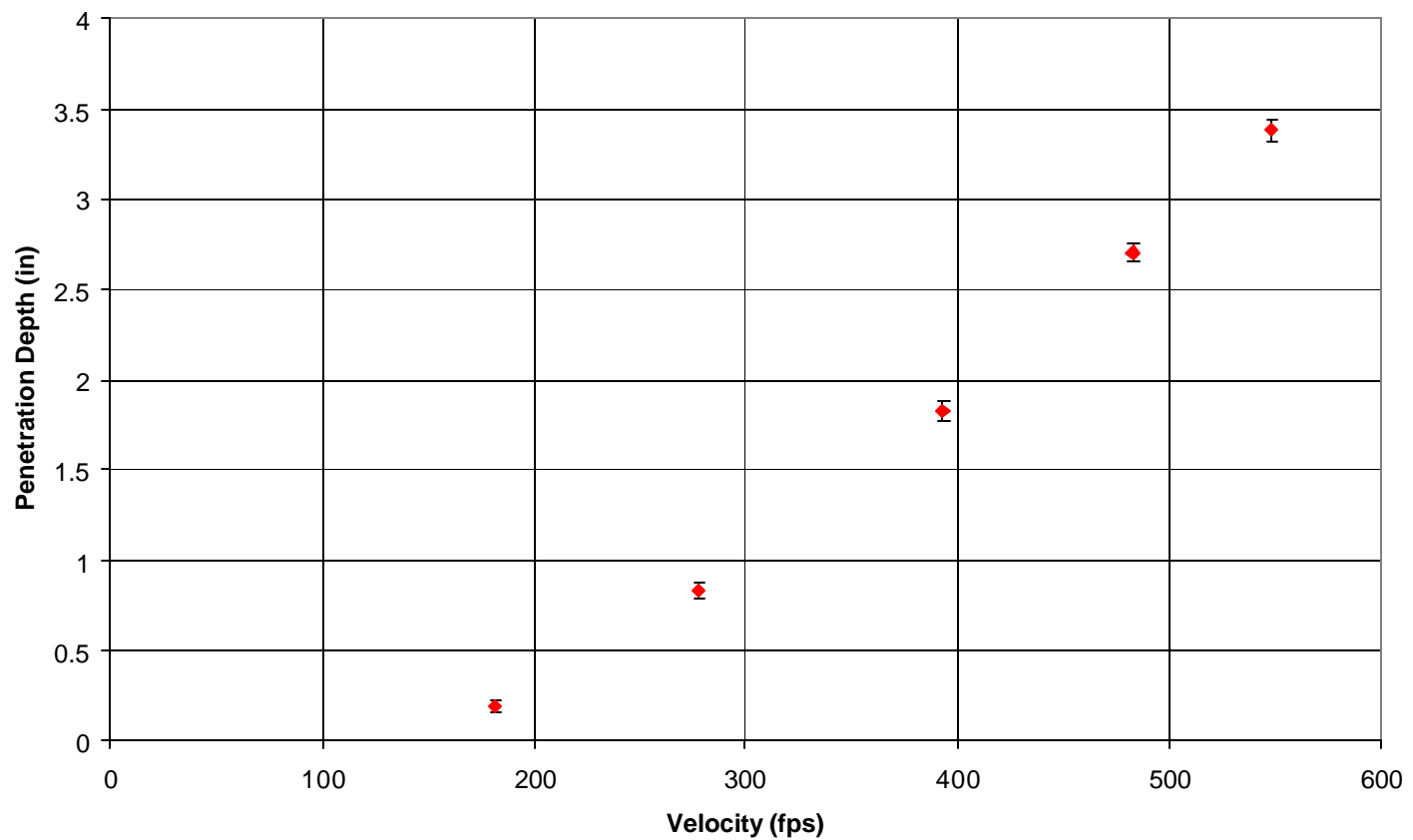




Styrofoam[®] Results

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4-inch Foam Penetration vs 0.32 Cal Stingball Velocity Calibration

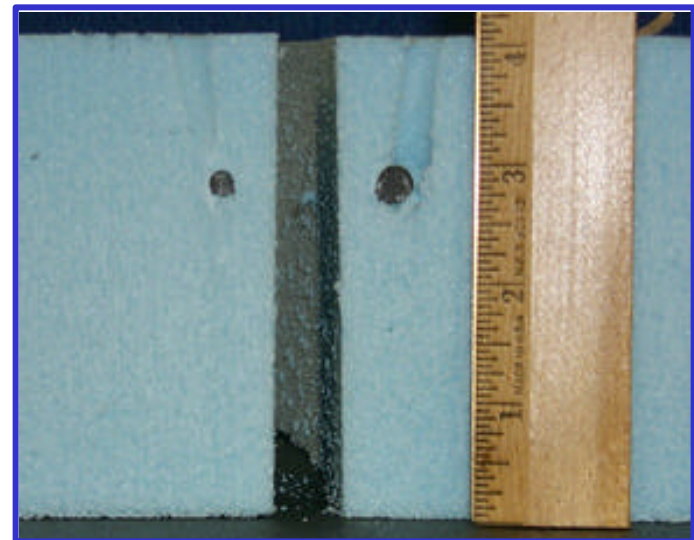




Discussion of Results

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- **Clay velocimeter**
 - good repeatability
 - better for higher velocity applications
 - heavy, labor intensive
 - low sensitivity, 600-fps/in
- **Styrofoam® velocimeter**
 - very good repeatability
 - light weight, easy to set up
 - reusable
 - high sensitivity, 115-fps/in





Summary

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- **Developed and demonstrated velocimeter to indirectly measure impact velocity**
- **Evaluated two materials, modeling clay and rigid Styrofoam® insulation**
- **Good correlation between impact velocity and penetration depth for 0.32 cal rubber stingballs**
- **Styrofoam® provides more sensitivity and is easy to handle.**
- **Modeling clay is heavy, and labor intensive, but may be better suited for higher velocity applications**
- **This technique shows promise in providing needed information for Human Effects Studies for NLW**



Recommendation

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Additional testing is required to expand usefulness:

- **Projectiles**
 - **vary size**
 - **shapes other than spherical**
 - **vary mass/density**
- **Velocimeter material**
 - **manufacture lot differences of Styrofoam®**
 - **other possible materials**
- **Expand velocity envelope for both low and high velocity applications**
- **Determine effects of environmental conditions**

An Indirect Method of Measuring Impact Velocity for Non-Lethal Weapons Blunt Trauma Studies

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Abstract

With greater emphasis on Non-Lethal Weapon (NLW) Systems, an accurate means of determining the human effects of these systems are required. Lethality and blunt trauma models, which are used to help predict the human effects, require many parameters to accurately define the NLW system. For NLW systems involving possible blunt trauma, the impact velocity of the munition must be known. There exists several techniques to measure the velocity of the munitions, each with benefits and drawbacks. The purpose of this paper is to describe an inexpensive and quick method of measuring the impact velocity of a blunt trauma stingball munition. Two velocimeters were constructed, one from commercially available rigid Styrofoam[®] insulation, and the other from modeling clay. Using a compressed gas gun, the implantation depths of .32 cal rubber stingballs were correlated with their impact velocity. This technique is being used in development of the XM99 Blunt Trauma Munition.

Introduction

During Non-Lethal Weapons (NLW) development programs, the determination of human effects, blunt trauma injuries and possible lethality are one of the most critical elements to the weapon's design and success. Unfortunately, many of the available blunt trauma and lethality models were originally developed for other applications such as determining the survivability of a person wearing ballistic armor. Even if the proper models existed, obtaining the necessary input conditions which describes the weapon system is typically not a trivial matter. One of the most important parameters needed for a lethality model is the impact velocity associated with a blunt trauma type weapon system. In the case of certain types of blunt trauma NLW, such as stingball grenades, which disperse large quantities of small rubber stingballs in random directions, the determination of an impact velocity is very difficult. Several methods are available but each has their limitations. High-speed video can be used, but typically the results are limited to at most a few stingballs per shot, because the camera must have an orthogonal view of the stingball's flight path. Also, if a pyrotechnic expulsion is used, the flash from the explosion may "white out" the camera's view. Another method uses high-speed x-rays. This technique avoids the "white out" problem, but x-ray measurements are expensive and data reduction is time consuming. Another technique uses two parallel foil or wire grid panels and requires the stingball to break through a grid or wire on each of the panels in order to determine the velocity.

An alternative method has been developed to determine the impact velocities of blunt trauma type weapons such as stingballs. This method correlated the impact velocities of stingballs to their corresponding implantation depths into both ordinary rigid construction Styrofoam^{®*}

* Registered Trademark of the Dow Chemical Company

insulation and modeling clay. The Styrofoam[®] velocimeter has been used during the development of the 66mm Non-Lethal (NL) XM99 Blunt Trauma Grenade.

Method Background

Two of the described impact velocity measurement techniques, high-speed video and x-rays, were used to support the XM99 program early on. Although both provided acceptable measurements, their associated limitations and expense, and the need for numerous optimization tests, created the necessity for a cheaper and faster method.

The XM99 grenade is a new NL munition system currently underdevelopment, and consists of three cardboard cylinders each containing hundreds of .32 cal rubber balls, Fig. 1, and launched from standard 66mm discharge tubes. With a range of 100m, a time fuze and a central burster, the XM99 is designed to function on the ground after arriving at the target. Upon functioning, hundreds of .32 cal rubber balls are propelled into the air in random directions at high rates of speed. The XM99 is intended for riot control situations where a blunt trauma device is deemed necessary. Figure 2 illustrates the concept of operations.

In order to assess the human effects of the XM99, one of the key parameters was the range of impact velocities associated with the stingballs. The determination of accurate impact velocities was crucial for the human effect studies and the optimization of the bursting charge. Due to the limited number of NLW standards, modification of an existing lethality standard was attempted. The “National Institute of Justice (NIJ) Standard for the Ballistic Resistance of Police Body Armor”¹ provides a “yes/no” determination of lethality for body armor, but is not directly suited for less-than-lethal applications. However, the standard uses modeling clay (Roma

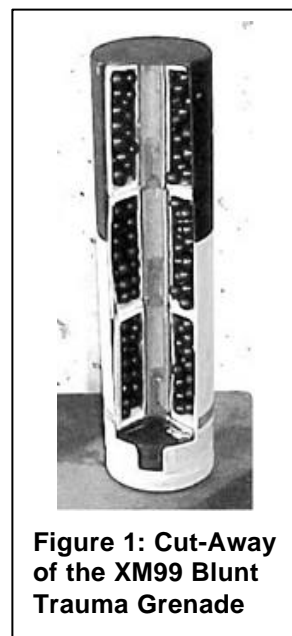


Figure 1: Cut-Away of the XM99 Blunt Trauma Grenade



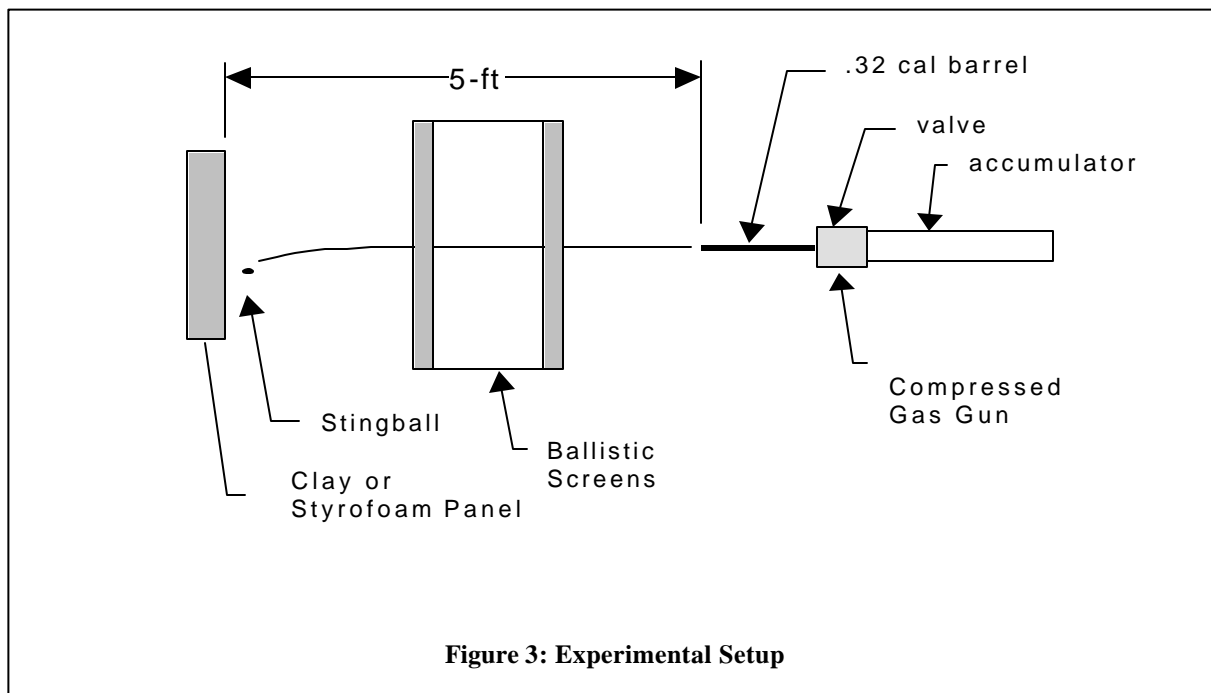
Figure 2: Concept of Operation of XM99

Plastilina No. 1) as a backstop behind the body armor and measures bullet penetration depth to determine “yes/no” lethality. Because of the required penetration repeatability of the clay to be a meaningful lethality standard, it was assumed that the clay could be “calibrated” to yield a quantitative measure of impact velocity. After initial assessment of the clay, its use as a repeatable velocimeter was verified, but due to its weight, lack of ease of handling, and labor intensive preparation of the backdrops before and after each shot, a more “user-friendly” material was sought. The backing material must be homogenous in order

to provide the needed repeatability. Ordinary 4-in thick construction Styrofoam[®] board was selected. This extruded polystyrene insulation is available in 4x24x96-in sheets. The Styrofoam[®] is inexpensive, lightweight, easy to handle, and yielded good correlation between impact velocity and penetration depth. Both the clay and Styrofoam[®] showed good potential in becoming a standard means of determining impact velocities for NLW.

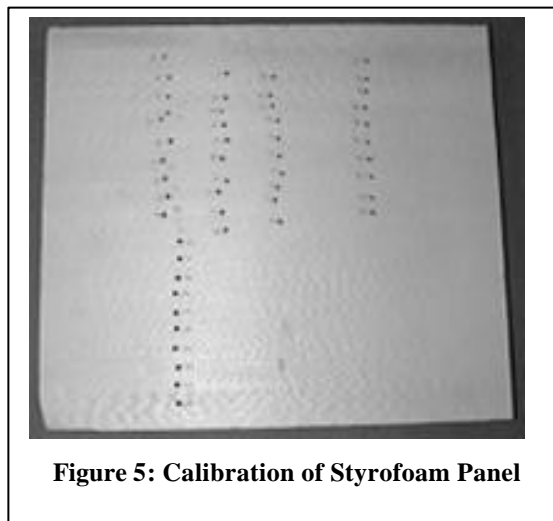
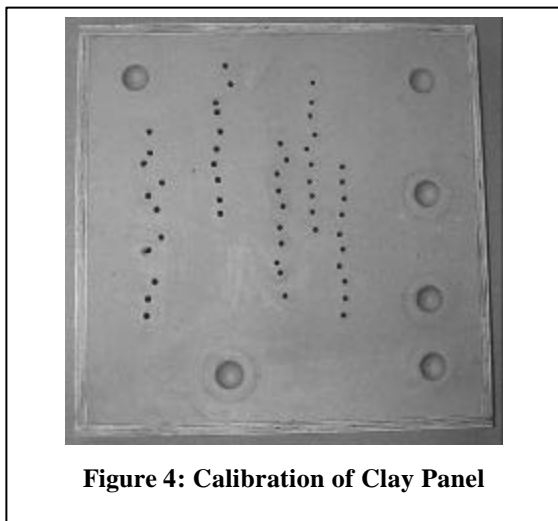
Calibration Procedure

In order for the clay or Styrofoam[®] to be acceptable as a velocimeter, repeatability is a requirement. Several panels, each of the clay and Styrofoam[®], were obtained. The clay was molded into 2x2-ft x 2-inch deep wooden boxes, which supported the clay on 5 sides, with the face side left open. Styrofoam[®] panels, 2x2-ft and 4-inch thick were cut and placed into frames for support. A small compressed gas gun was modified to shoot .32 cal stingballs. Figure 3 presents a sketch of the equipment layout used in calibrating the foam and the clay panels.



Calibration consisted of correlating the stingball's impact velocity, generated by the compressed gas gun and measured with ballistic screens, to the stingball's depth of penetration into the clay or foam. Ten shots each were made at five different velocities ranging from approximately 180 to 550-fps. The 180-fps was the lowest repeatable velocity that could be obtained with the gas gun due to the stingball's size and mass. Whereas, the 550-fps represented the upper limited on both the stingball causing severe blunt trauma, and complete penetration through the foam. The procedure for the calibration test was as follows. A stingball was muzzle loaded into the gas gun barrel. The accumulator was pressurized to the appropriate pressure, and the gun fired. The stingball velocity was recorded through the ballistic screens and the impact position on the clay or foam was labeled. The panel was raised a couple of inches and another shot was made using the same procedure. This was repeated for a total of ten shots at each pressure/velocity. The panel was then repositioned horizontally and the entire process repeated for the remaining velocities. Figures 4 and 5 show the clay and Styrofoam[®] panels after all 50 shots were

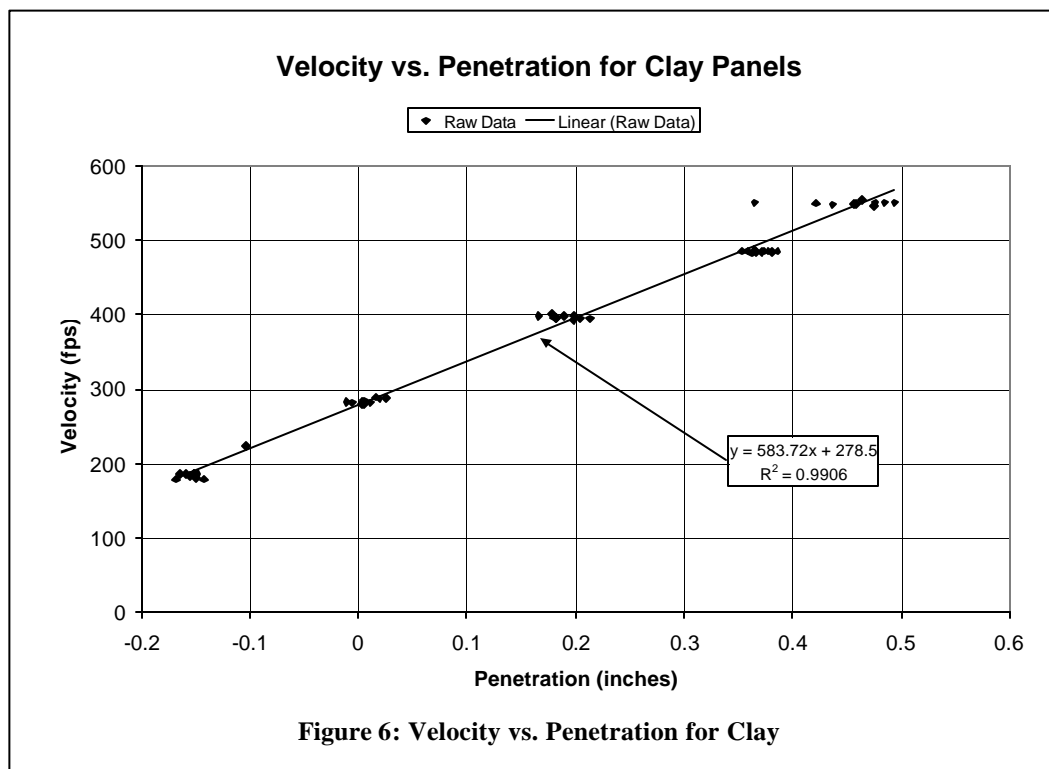
completed. Please note that the large indentations in the clay were made by a calibration slug required by the NIJ standard to assure that the clay was of the proper consistency.



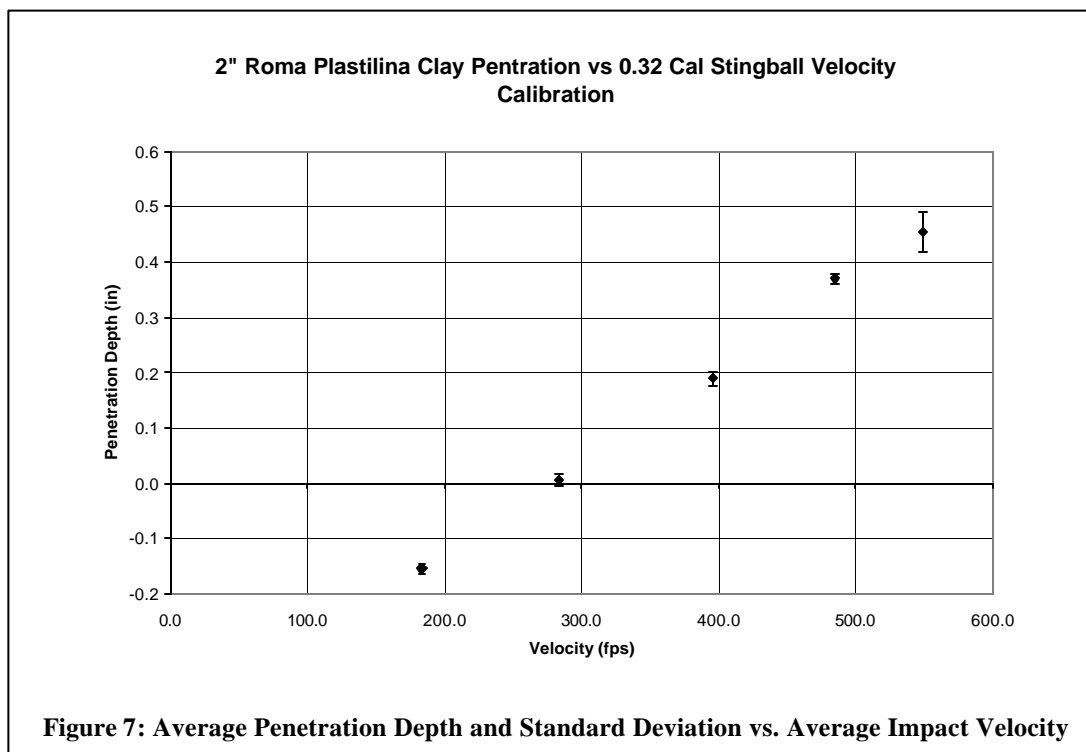
After all stingballs had been shot, the impact depth was measured. Each hole was cleaned out to remove any fragments of clay or Styrofoam[®] that may interfere with the depth measurements. Stingball penetration was measured to the aft end of the ball using a machinist depth gauge.

Results

The tabulated results from both the clay and Styrofoam[®] were plotted and a linear curve fitted to the data. Figure 6 shows the plotted results for clay panels and the corresponding linear curve



fit. The average penetration and corresponding standard deviation is plotted against the average velocity in Fig. 7. Repeatability of the stingball penetration is very good, below 500-fps and fair



above. Please note that since the penetration depth is measured relative to the aft end of the stingball, below 280-fps the penetration depths were negative, because the balls were sticking above the surface. For the velocity range of approximately 180 to 550-fps, the change in penetration depth was less than 0.75-in, which corresponds to a sensitivity of 600-fps/in.

Figure 8 shows the resulting stingball penetration depths versus impact velocity into the 4-in thick Styrofoam[®] panel. A linear curve was fitted to these data with excellent correlation and is presented in Fig. 8. Figure 9 presents the average stingball penetration depth and standard deviation versus the average impact velocity. The Styrofoam[®] provides excellent penetration repeatability even at the highest impact velocities. Over the velocity range tested, the change in penetration depth was over 3-in, yielding a sensitivity of 115-fps/in.

Discussion

Both the clay and the Styrofoam[®] provided good repeatability over the desired range of impact velocities. The Styrofoam[®] panels were selected for the XM99 optimization tests for a number of reasons. Mass was a big factor. The clay panels weighed approximately 90-lb as opposed to less than 1-lb for the Styrofoam[®]. The Styrofoam[®] provided greater sensitivity to velocity variations by a factor of five when compared with the clay. Preparation time for new clay panels was over three hours and very labor intensive. Repairing and resurfacing each of the clay panels after each test would have taken at least an hour. The foam on the other hand required very little preparation and labor, only the time required to cut the panels to size and fit them into the support frame. If properly labeled the foam panels could be reused for several tests. Because

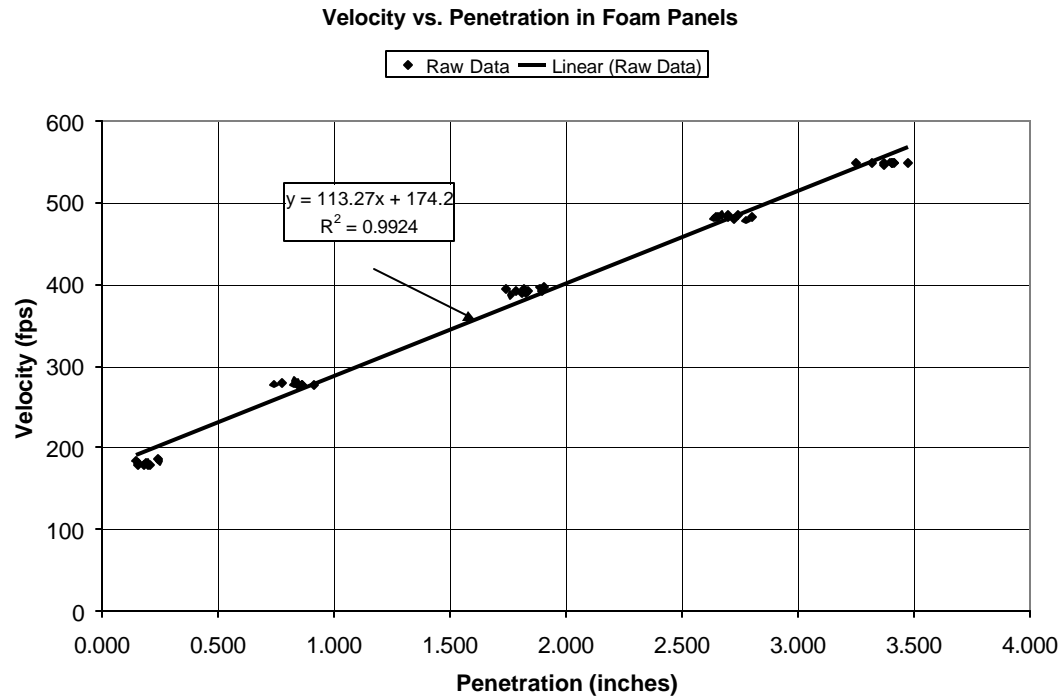


Figure 8: Velocity vs. Penetration for Styrofoam

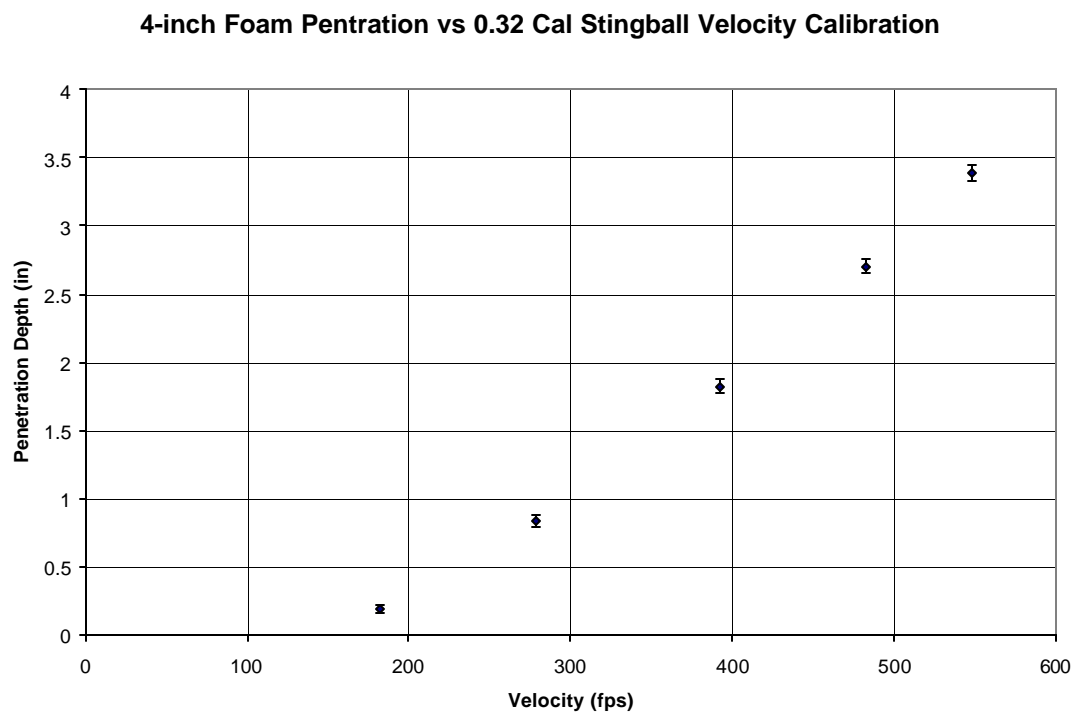


Figure 9: Average Penetration Depth and Standard Deviation vs. Average Impact Velocity

of cratering at the stingball impact sites, and other debris marring the clay surface, the clay was only usable for one test. The clay panels would be a good choice for extremely high impact velocities, approaching sonic speeds. For the .32-cal stingballs, the 4-in foam panels were limited to an upper velocity of 550-fps. Beyond this velocity limit, the balls would penetrate completely through the panels.

The upper velocity limit for using the Styrofoam® will depend on the availability of the thicknesses above 4-in. Early during the development of the foam velocimeter, increased foam thickness was achieved by layering several thinner pieces of foam together. This did not work due to the interaction between the foam layers. The stingballs had a tendency to try and create conical plugs, which were blown out the backside of the first layer. These plugs had a diameter several times the diameter of the balls and greatly impeded their attempt to penetrate the subsequent layers. In order to work properly the foam must be one layer of the appropriate thickness.

Numerous foam panels have been used in the optimization testing of the XM99 grenades. A typical example of one of these test panels is shown in Fig. 10. Each stingball impact site is labeled. Several large pieces of the cardboard grenade body can also be seen imbedded in the foam. The penetration depth for each labeled stingball can be measured either by using a depth gauge or by cutting through the foam at each impact location and directly measuring the depth. Figure 11 shows a cross section of a piece of foam, which has been cut with a bandsaw. This

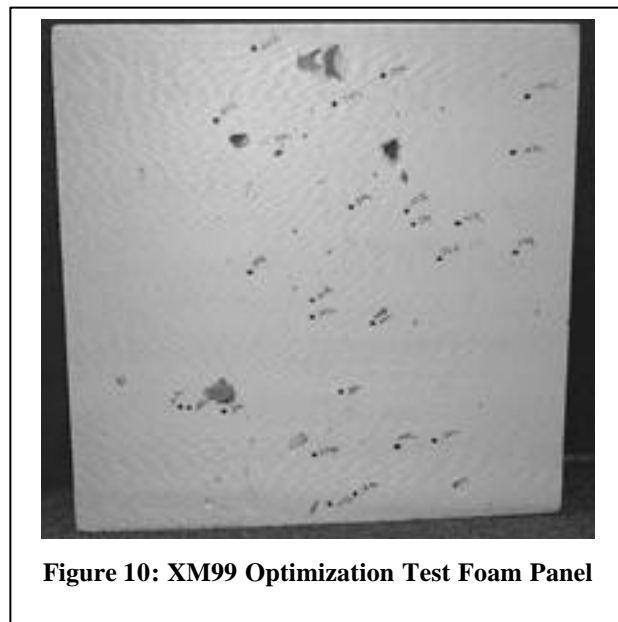


Figure 10: XM99 Optimization Test Foam Panel

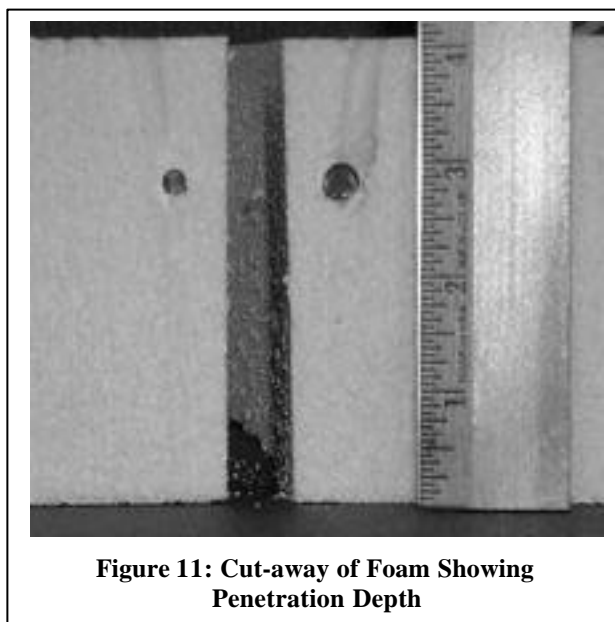


Figure 11: Cut-away of Foam Showing Penetration Depth

technique does not appear to disturb the stingball, thus does not increase or decrease the depth of penetration. For the example illustrated in Fig. 11, the stingball has a penetration depth of approximately 1.125-in, which corresponds to an impact velocity of 301-fps.

Summary

The development of a velocimeter to indirectly measure the impact velocity of NLW systems has been developed and demonstrated. Two different materials, modeling clay and rigid construction

insulation, were evaluated, and both provided good correlations between impact velocity and penetration depth for .32 cal rubber stingballs. The Styrofoam[®] insulation was more sensitive, lighter weight and easier to handle than the clay. The clay was more labor intensive to prepare but allowed testing of much higher velocities than could be achieved with the current foam. This technique shows promise in assisting with the human effects modeling necessary for the proper design of current and future blunt trauma type NLW systems.

Recommendations

Additional testing is needed to extend this technique beyond the current application. Effects due to size, mass and external shape of the projectile should be tested. Differences in the Styrofoam[®] insulation between manufacture's lots must be investigated. Other materials for the velocimeter should be analyzed in order to extend the lower and upper limits of the velocity range. Finally, panel edge effects and ambient temperature sensistivity should be identified.

References

¹ "National Institute of Justice Standard for the Ballistic Resistance of Police Body Armor", NIJ Standard-0101.03, April 1987